PB84-177856

Effects of Traffic Speed on the Ambient Pollutant Concentration Near Roadways

New York State Dept. of Environmental Conservation, Albany

Prepared for

Environmental Sciences Research Lab.
Research Triangle Park, NC

1984

U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-177856

EPA-600/D-84-102
April 1984

EFFECTS OF TRAFFIC SPEED ON THE AMBIENT POLLUTANT CONCENTRATION NEAR ROADWAYS

by

W. B. Petersen and R. E. Eskridge
Meteorology and Assessment Division
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

and

S. T. Rao and V. Pagnotti
Division of Air
NYS Department of Environmental Conservation
Albany, NY

EPA Grant 810475-01

EPA Project Officer
W. B. Petersen

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U. S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/D-84-102	2.
3. RECIPIENT'S ACCESSION NO. PB84 177856	
4. TITLE AND SUBTITLE EFFECTS OF TRAFFIC SPEED ON THE AMBIENT POLLUTANT CONCENTRATION NEAR ROADWAYS	5. REPORT DATE 1984 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) W.B. Petersen, R.E. Eskridge, S.T. Rao, V. Pagnotti	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Sciences Research Laboratory Office of Research and Development U. S. Environmental Protection Agency Research Triangle Park, NC 27711	10. PROGRAM ELEMENT NO. C9YA1C/04-2290 FY(84) 11. CONTRACT/GRANT NO. 810475-01
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Sciences Research Laboratory--RTP,NC Office of Research and Development U. S. Environmental Protection Agency Research Triangle Park, NC 27711	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA/600/09
15. SUPPLEMENTARY NOTES	

16. ABSTRACT

In the numerical roadway model, the vehicle wake diffusion is dependent upon the turbulent kinetic energy, which is proportional to the square of the relative wind speed on the moving vehicles. This model predicts that turbulent mixing and hence pollutant concentration on and downwind of the roadway are dependent on the vehicle speeds. The Long Island Expressway CO data provide an opportunity to test the theoretical predictions on the effect of traffic speed on the ambient concentrations. It is observed that the traffic speed does not affect the dispersion process as long as the ambient atmospheric conditions are neutral or unstable. Sufficient data are not available to quantify the role of traffic speed on the ambient concentrations downwind of the roadway under stable atmospheric conditions. Since commonly used Gaussian dispersion models do not account for traffic generated turbulence properly, it is possible that the current versions of these models underestimate pollutant concentration adjacent to the roadway under stable atmospheric conditions with low traffic speeds.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED 20. SECURITY CLASS *(This page)* UNCLASSIFIED	21. NO. OF PAGES 18 22. PRICE

EPA Form 2220-1 (9-73)

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

INTRODUCTION

Models currently available for assessing air quality downwind of roadways do not incorporate the effects of traffic generated turbulence as a function of vehicle speed. The popularly used models, HIWAY-2[1] and CALINE3[2], were developed from data bases which contain predominantly high speed traffic and therefore may have a limited range of traffic speeds over which they are applicable. Recently a numerical model (ROADWAY) developed by Eskridge et al.[3], included vehicle wake diffusion dependent upon the turbulent kinetic energy which is proportional to the square of the relative wind speed on the moving vehicle. This model predicts that turbulent mixing and hence pollutant concentrations on and downwind of a roadway are dependent on the vehicle speeds. The vehicle wake turbulence is strongest over the roadway and decreases rapidly from the road. The wake theory predicts that this effect will be most important under stable atmospheric conditions and much less important under neutral and unstable conditions. The Long Island Expressway CO data[4] provide an opportunity to investigate the theoretical predictions of the effect of traffic speed on concentrations downwind of the expressway.

ANALYSIS

One of the main assumptions made in the ROADWAY model is that a reference atmosphere describable by similiarity theory exists on which the perturbations due to the vehicles can be added, i.e., the eddy diffusion coefficients from similarity and wake theories can be added. Similiarly, the wake velocity deficit is added to the wind field predicted by similarity theory. The vehicle wake theory was originally developed by Eskridge and Hunt[5]. It was later modified and evaluated in wind tunnel experiments by Eskridge and Thompson[6] and Eskridge and Rao[7]. Better understanding of vehicular turbulence and its associated effects on concentrations downwind of roadway provided the motivation for the development of a numerical line source model incorporating a wake theory. It is evident from the theory that the model is capable of assessing the impact of vehicular emission on air quality for different vehicle speeds. Currently formulated highway models like HIWAY-2 and CALINE3 are incapable of assessing this effect. These models only reflect the change in emissions for different vehicle speeds and not the change in the turbulent intensities caused by the vehicle wakes for different vehicle speeds.

In order to determine the sensitivity of ROADWAY to different input vehicle speeds, the model was executed for vehicle speeds of 100, 80, 60, 40, and 20 km/hr for different atmospheric stabilities. The results are shown in Figures 1 through 4. Emission rate, wind speed and direction remained constant for all model runs of the same stability class. In Figure 1 concentration versus downwind distance is plotted for the five vehicle speeds for the case when the atmosphere was characterized as unstable. Figure 2 shows model runs for stable conditions. A receptor height of 1.5m was used in the model runs to develop Figures 1 and 2. Both figures display significant sensitivity of predicted concentration to vehicle speed especially for receptors close to the road. The ratio of peak concentrations for vehicle speeds of 20 km/hr to those for vehicle

speeds of 100 km/hr for unstable and stable conditions are approximately 11 and 15 respectively. Both figures also show a very large increase in peak concentrations when vehicle speeds drop from 40 km/hr to 20 km/hr. Concentrations downwind of the road are influenced by vehicle speed at much greater downwind distances for stable conditions. At 60m downwind concentrations have dropped by a factor greater than five from the peak concentration for unstable conditions. However, at the same downwind distance concentrations have dropped by a factor slighty over two for stable conditions. These figures show that the turbulence generated by vehicular wakes dominates dispersion for stable and unstable conditions in the near field but during unstable conditions ambient turbulence quickly dominates the dispersive process.

Figures 3 and 4 are plots of vertical concentration profiles for five different vehicle speeds for unstable and stable conditions, respectively. Wind speed and direction were held constant. The concentration profiles were generated at a downwind distance of 15m from the road's edge. For unstable conditions, concentrations above background extend up to 20m. However, at a height of 10m it would be difficult to distinguish any traffic speed effect. For stable conditions (Figure 4) the traffic speed effect is quite large near the surface but above 6m there is little traffic speed effect on the concentration field. Note the change from Figure 3 to Figure 4 in the concentration scale. In Figures 3 and 4 we see an analogous result to that observed in Figures 1 and 2. During stable conditions concentrations downwind were affected by traffic generated turbulence more than during unstable conditions. The ratios of the concentrations at each height above the ground for traffic speeds of 20 km/hr to 100 km/hr are always larger for stable atmospheric conditions. For both stable and unstable conditions there is a large increase in concentration when the traffic speed is reduced from 40 km/hr to 20 km/hr.

The previous figures have suggested a relationship among atmospheric stability, vehicle speed, and roadside concentrations. In Figure 5 concentrations at 2m adjacent to the road at a height of 1.5m are plotted for stable, neutral and unstable conditions. The ratio of the concentration during stable conditions to the concentration during unstable conditions increases only slightly from 2.2 at 80 km/hr to 2.8 at 20 km/hr, indicating that dispersion adjacent to the roadway is dominated by traffic generated turbulence. While concentrations continue to decrease for higher vehicle speeds, large changes are predicted for speeds less than 40 km/hr.

The variation in CO concentrations adjacent to a roadway for different vehicle speeds was investigated using the Long Island Expressway data[4]. Releases of SF_6 tracer were performed when traffic was freeflowing. Thus, only the high speed traffic effects can be deduced from the SF_6 data. However, a CO data set of 303 hours for traffic speeds from 32 km/hr to 89 km/hr (20 to 55mph) was available for analysis. Lowest traffic speeds were observed from 6 am to 9 am on the west bound lanes where average traffic speeds were about 48 km/hr. In the evening traffic speeds reached a low of 32 km/hr between 4 pm to 5 pm and remained fairly low through 7 pm. At all other times traffic speeds were either 80 km/hr or 89 km/hr. CO emissions along the roadway are a function of traffic volume and speed. The sensitivity of the ROADWAY model to traffic speed effects, discussed in the

first part of this paper, were made by assuming a constant emission rate unrelated to traffic volume. However, in actual applications traffic volume and speed are related. One would expect CO emissions to increase for lower traffic speeds and higher traffic volumes. CO emission strengths were computed using Mobile-2[8] for each hour for each direction of traffic. Average CO emission strength for different times of the day are displayed in Figure 6. The dotted line indicates times when there were no data. Highest emissions occurred during the morning hours around 7 am from the west bound traffic heading toward New York City. Maximum emissions in the afternoon occurred between 4 pm to 5 pm for the east bound traffic. Although the maximum hourly traffic volume in the afternoon was only 2% larger than the maximum hourly traffic volume in the morning[4], the maximum source strength in the afternoon is approximately 18% larger than the maximum source strength in the morning. The large increase in the source strength in the afternoon is primarily due to lower traffic speeds.

Figure 7 shows average concentration for the nearest roadside receptor as a function of time of day. Although maximum source strength occurred in the afternoon, maximum roadside CO concentrations occurred during the morning hours. Higher concentrations in the morning are due to lower average wind speeds, shown in Figure 8. Concentrations normalized by wind speed and emission rate "Q" are plotted as a function of time of day in Figure 9. Also plotted on the same figure are the traffic speeds for each hour of the day. Vehicle speeds are low in the west bound lanes in the morning hours and remain at high speeds the rest of the day. East bound traffic has low vehicle speeds in the afternoon with high vehicle speeds the rest of the day. Normalized concentrations are very high when traffic volumes are low. Associated with low traffic volumes are low emission rates and high traffic speeds. However, normalized concentrations are low when traffic speeds are low and emissions are high. As Q increases with higher traffic volumes and lower vehicle speeds the normalized concentration should become smaller. As the traffic generated turbulence decreases with higher traffic volumes and lower vehicle speeds the normalized concentration should become larger. This figure suggests that changes in emission strength are accounting for increased concentrations adjacent to the road for low traffic speed conditions more than a decrease in the turbulent kinetic energy due to a decrease in vehicle speed.

To further investigate the relationship of normalized concentrations and vehicle speed a portion of the data are plotted in Figure 10. In this analysis, we considered data representing only parallel wind-road orientation since the traffic speed in the west bound and east bound directions are different during the peak traffic hours. We took the emission strength for the direction having low traffic speed and the concentration at the receptor nearest to that direction in computing the normalized concentration. Parallel wind cases were chosen to reduce the influence of the traffic generated turbulence from the high speed traffic on the opposite side of the roadway. The average emission rate versus vehicle speed is also displayed on the right scale in Figure 10. The solid and dashed lines are the regression lines through the average normalized concentrations and the average emission rates respectively. If the change in the normalized concentration for different vehicle speeds is due primarily to changes in Q, then the slopes of the regression lines ought to have similar magnitudes but different signs. The slope of the regression line through the normalized concentrations is 9.0, while the slope of the regression line through the

Q's is -10.0. Figure 10 like Figure 9 shows that the change in the normalized concentration for different vehicle speeds is due primarily to changes in the emission rates. This data base is comprised mostly of unstable and neutral atmospheric conditions. Under these situations the ambient conditions may dominate the traffic effects. However, when the atmosphere is extremely stable the traffic effects should dominate the near-field diffusion. Thus, we might expect that near-field diffusion which is a combination of ambient atmospheric turbulence and traffic effects will be such that the pollutant concentrations immediately downwind of the roadway will not exhibit significant variation for different stability regimes. The Long Island Expressway data do not contain many hours when the atmosphere was stable and no hours of data when traffic speeds were low under stable conditions. Therefore, we cannot assess the influence of traffic speed on roadside concentrations for stable atmospheric conditions.

CONCLUSIONS

Although ROADWAY predicts the greatest traffic speed effect on concentrations during stable conditions, the model predicts that the concentration field should still be significantly affected by traffic generated turbulence during unstable conditions near the roadway. For these CO data the traffic speed effect on the concentration field was not observed for unstable atmospheric conditions. The effects on the concentration field due to traffic generated turbulence for different vehicle speeds are small when compared to changes in emission rates for different vehicle speeds. The paucity of hours of stable situations, the uncertainties in emissions and the uncertainties in traffic speeds made it difficult to see any traffic speed effect on concentrations. The vehicular emissions from the roadway were estimated using the arithmetic mean vehicle speed. However, in computing the mean vehicle speed for input into the wake model, the square root of the sums of the squares of vehicle speed should be computed. This value is more closely associated with the energy production. To effectively test the ROADWAY model one would like to see the GM test track revisited allowing the packs of cars to run at predescribed speeds. Using a tracer and running all the vehicles at predescribed speeds for a variety of atmospheric conditions would eliminate the uncertainties which made it difficult to discern the traffic speed effect.

Acknowledgements

One of the authors (S.T. Rao) gratefully acknowledges the support of this investigation by the U.S. Environmental Protection Agency under grant No. CR-810475-01. Thanks are extended to Mr. Gary Lamphear and Mrs. Carol Clas for thier help in drafting of the figures.

REFERENCES

1. Petersen, W.B., 1980: "User's Guide for HIWAY-2: A highway air pollution model," EPA-600/8-80-018, 69 pp.

2. Benson, P.E., 1979: "CALINE3 - A versatile dispersion model for predicting air pollutant levels near highways and arterial streets," FHWA/CA/TL-79/23, 129 pp.

3. Eskridge, R.E., F.S. Binkowski, J.C.R. Hunt, T.L. Clark and K.L. Demerjian, 1979: "Highway modeling: Part II - Advection and diffusion of SF_6 tracer gas," J. Appl. Meteor., 18, 401-412.

4. Rao, S.T., M. Keenan, G. Sistala, and P. Samson, 1979: "Dispersion of pollutants near highways - data analysis and model evaluation," EPA-600/4-79-011, 158 pp.

5. Eskridge, R.E., and J.C.R. Hunt, 1979: "Highway modeling: Part I - prediction of velocity and turbulence fields in the wakes of vehicles," J. Appl. Meteor., 18, 387-400.

6. Eskridge, R.E., and R.S. Thompson, 1982: "Experimental and theoretical study of the wake of a block-shaped vehicle in a shear-free boundary flow," Atmos. Environ., 16, 2821-2836.

7. Eskridge,R.E., and S.T. Rao, 1983: "Measurement and prediction of traffic-induced turbulence and velocity fields near roadways," J. Climate and Appl. Meteor., 22, 1431-1443.

8. "User's Guide to MOBILE2, Mobile Source Emissions Model," U.S. Environmental Protection Agency, EPA-460/3-81-006, February, 1981.

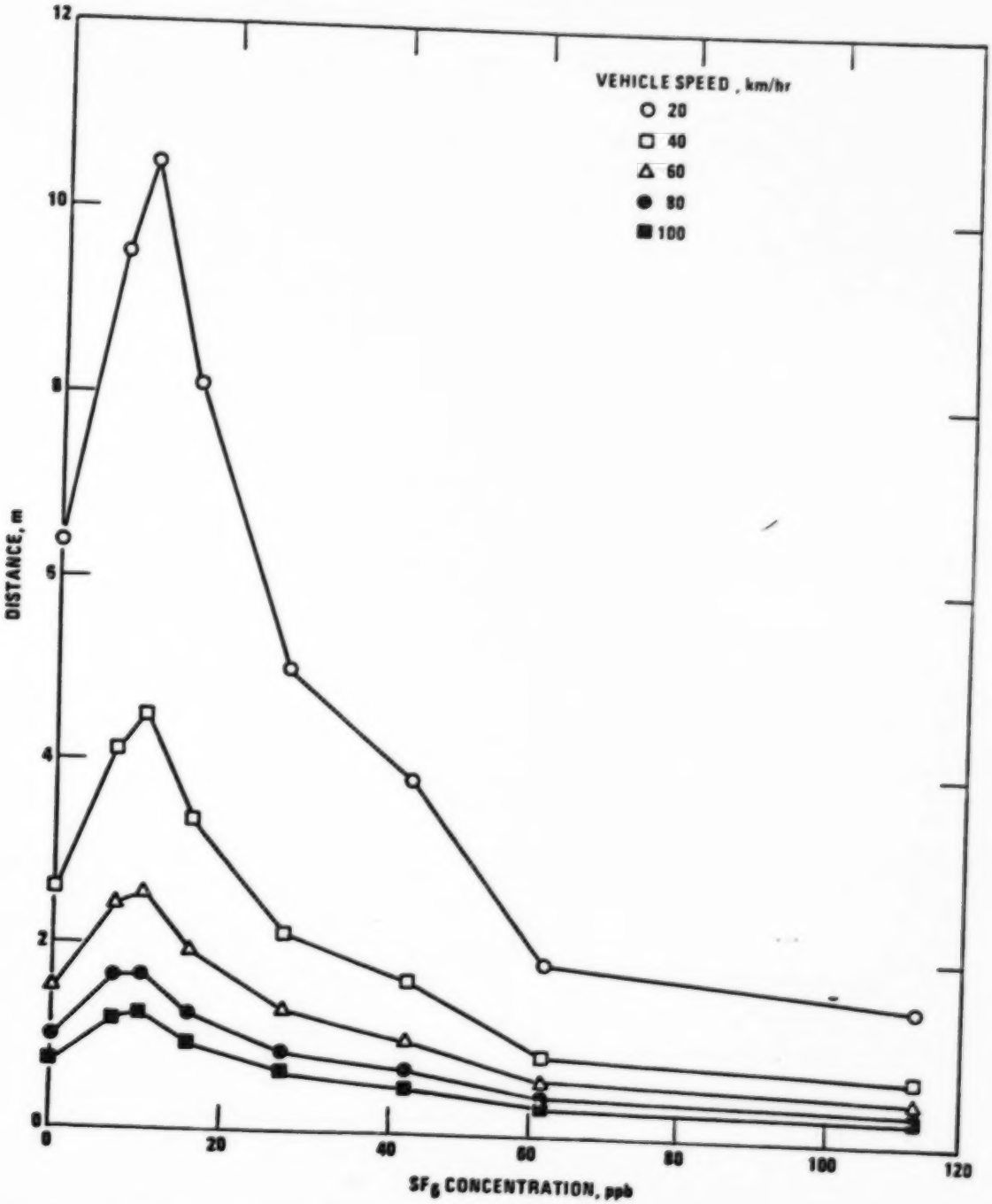

Figure 1. Concentration versus downwind distance for five vehicle speeds: 100, 80, 60, 40, and 20 km/hr for unstable atmospheric conditions.

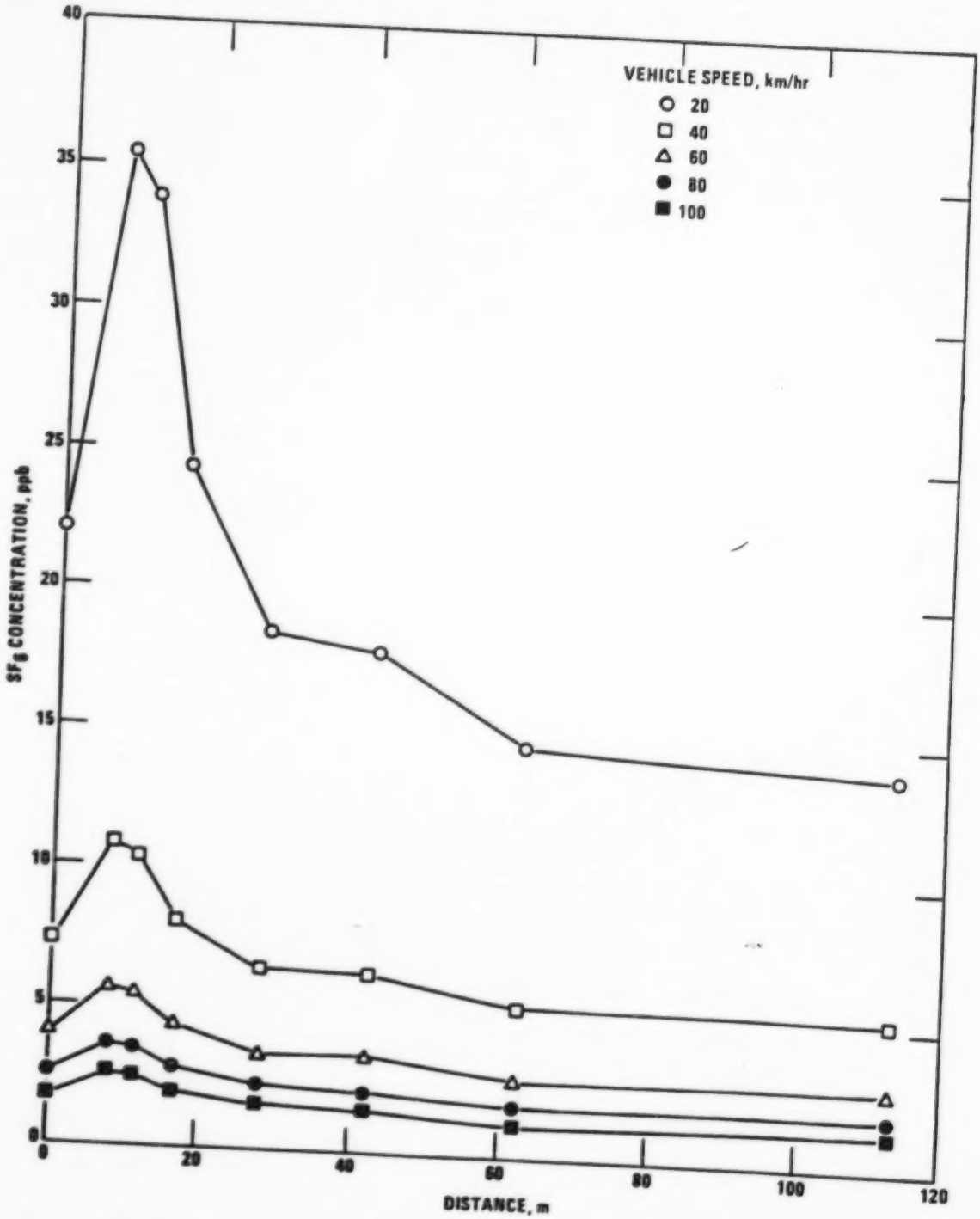

Figure 2. Concentration versus downwind distance for five vehicle speeds: 100, 80, 60, 40, and 20 km/hr for stable atmospheric conditions.

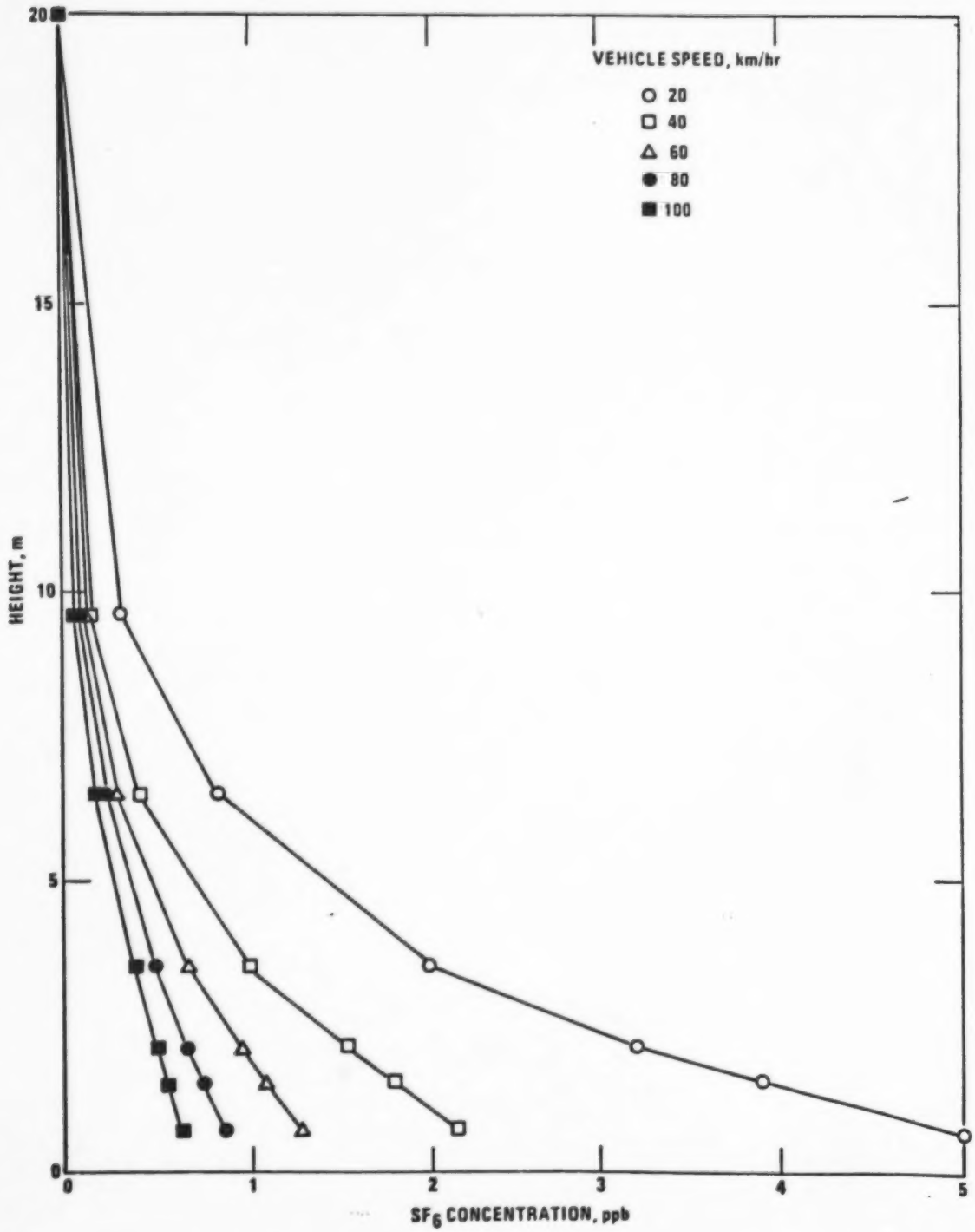

Figure 3. Concentration versus height for five vehicle speeds: 100, 80, 60, 40, and 20 km/hr for unstable atmospheric conditions at 15 m downwind of roadway.

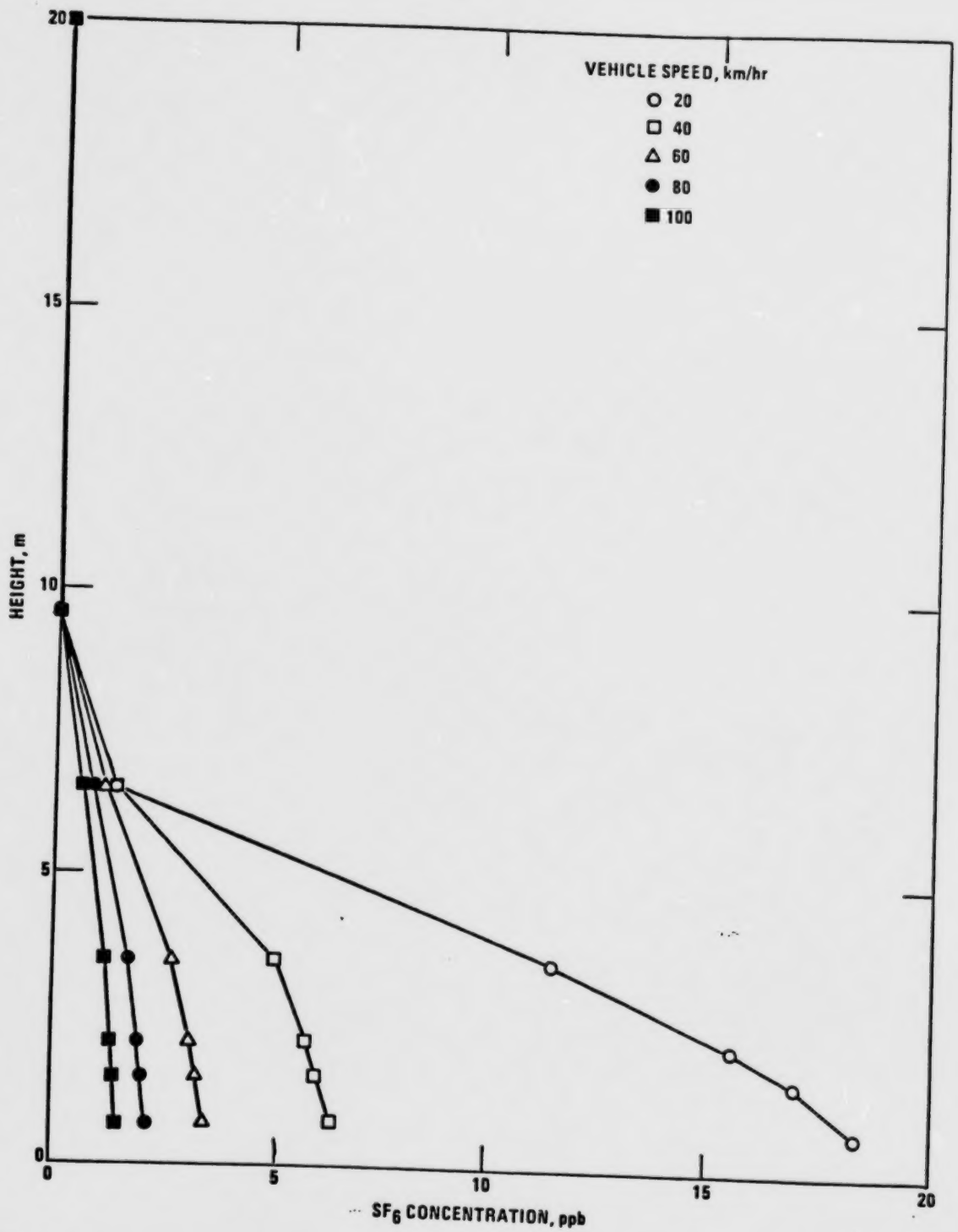

Figure 4. Concentration versus height for five vehicle speeds: 100, 80, 60, 40, and 20 km/hr for stable atmospheric conditions at 15 m downwind of roadway.

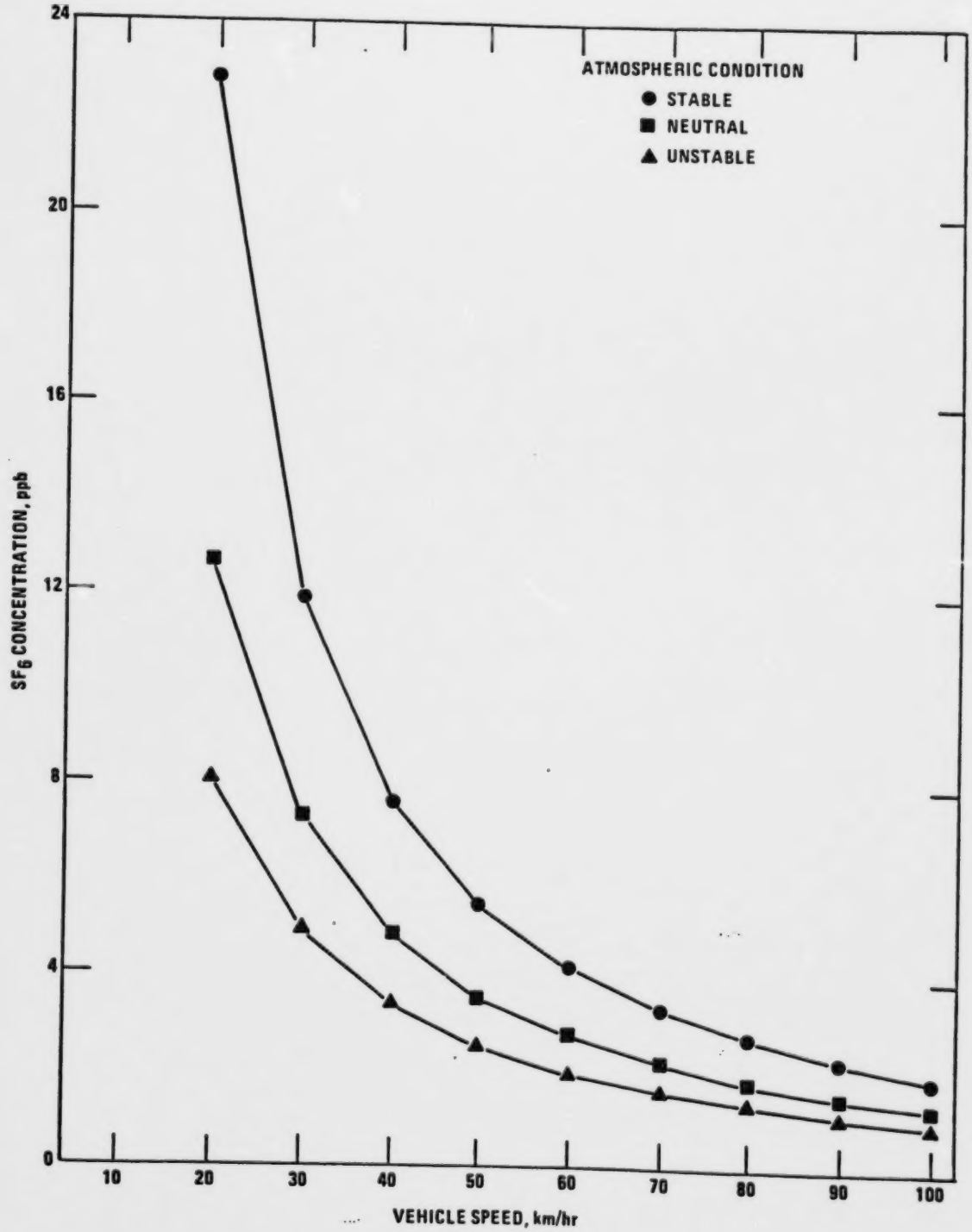

Figure 5. Concentration versus vehicle speed for unstable, neutral, and stable atmospheric conditions at 2 m downwind of roadway.

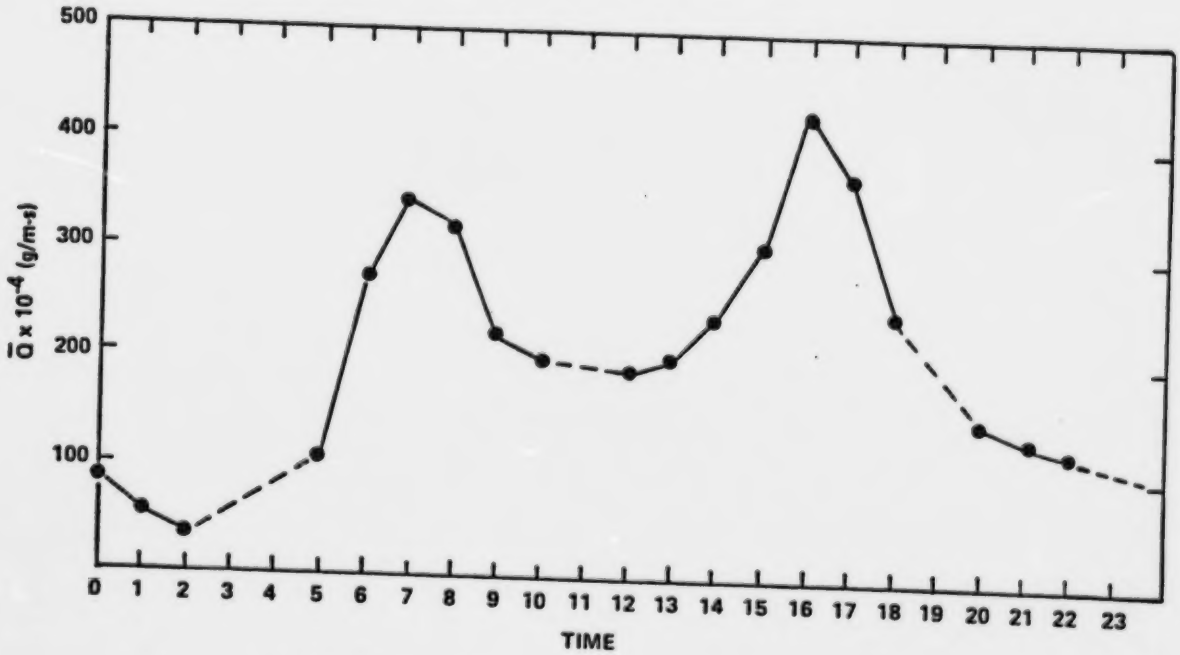

Figure 6. Average CO emission strength versus time of day.

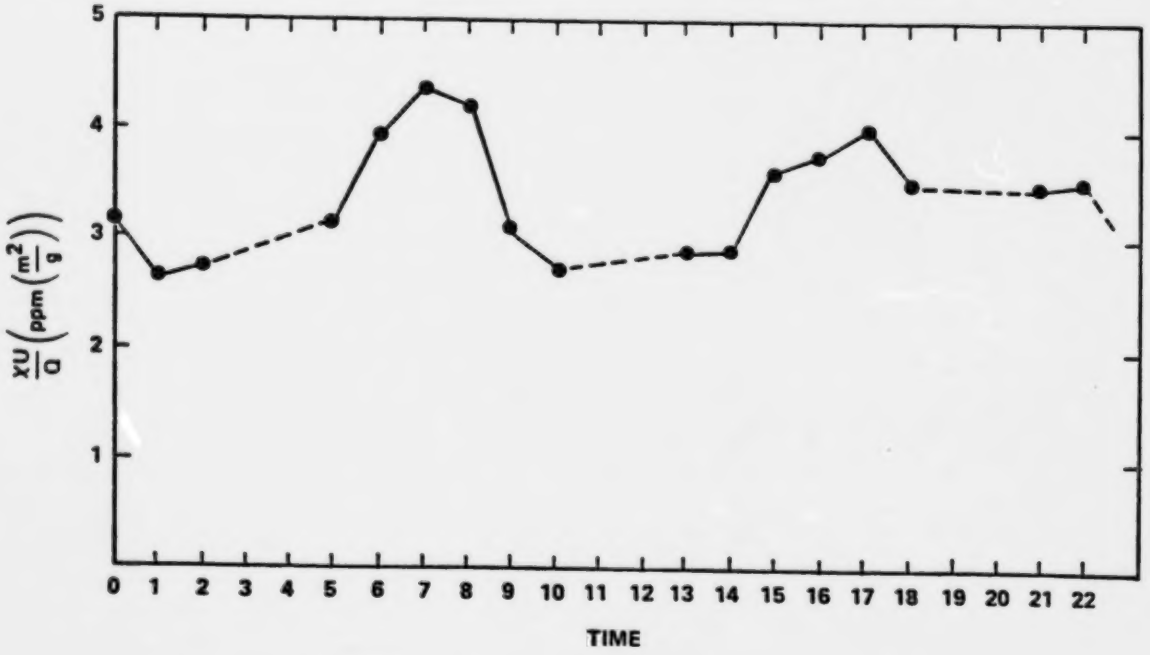

Figure 7. Average CO concentration for nearest roadside receptor versus time of day.

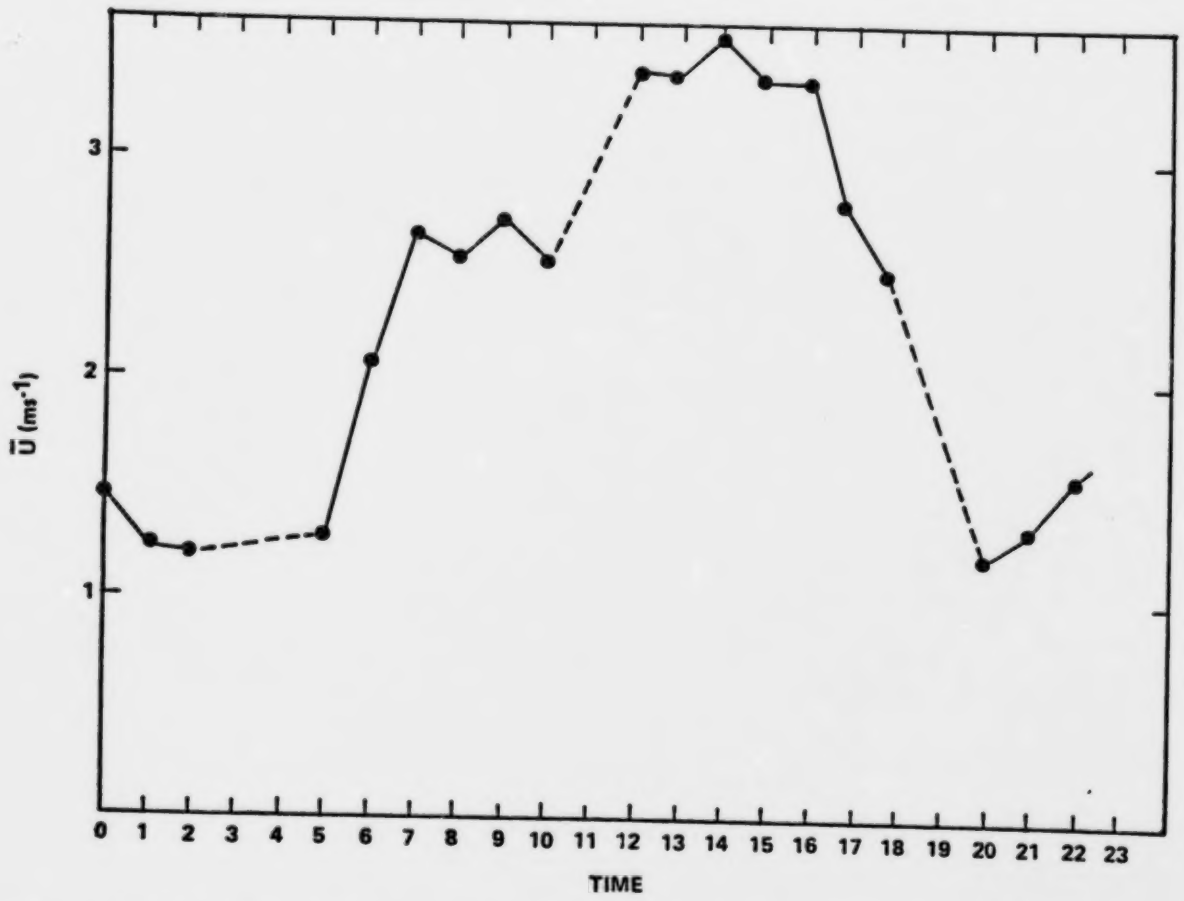

Figure 8. Average wind speed at nearest roadside receptor (ground level) versus time of day.

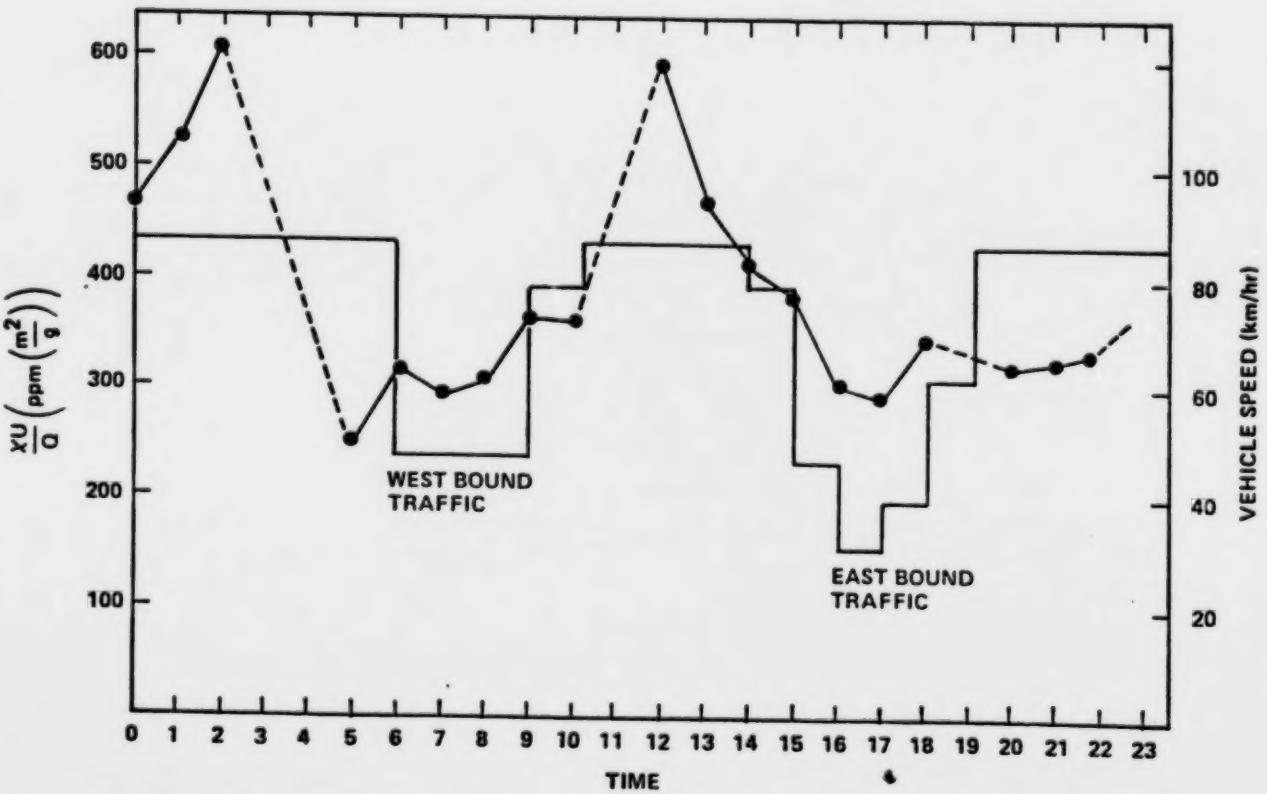

Figure 9. Normalized concentration at nearest roadside receptor (ground level) versus time of day. Average vehicle speed is indicated on the right scale.

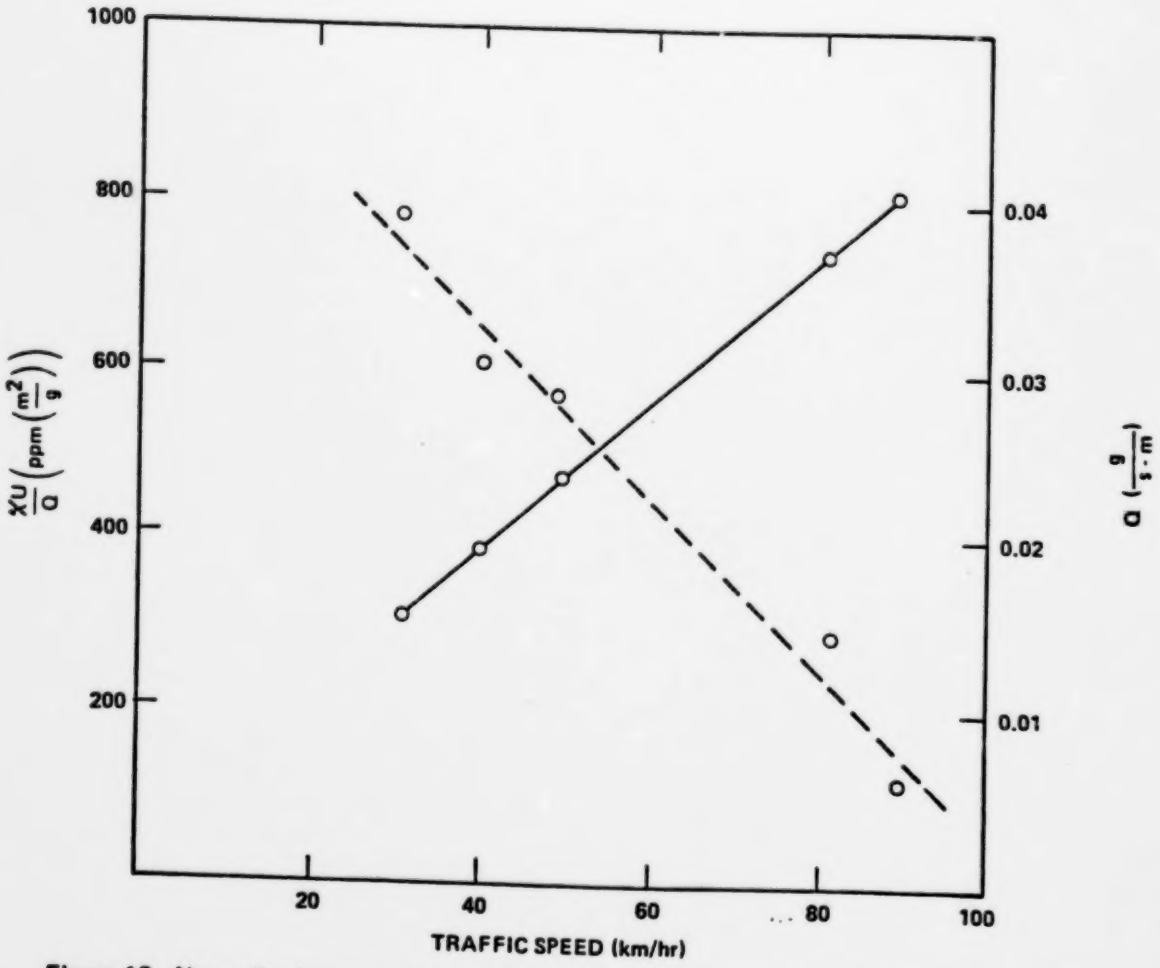

Figure 10. Normalized concentration versus vehicle speed for parallel wind cases (255°-285°, 75°-105°). Emission rate "Q" is indicated on the right scale.